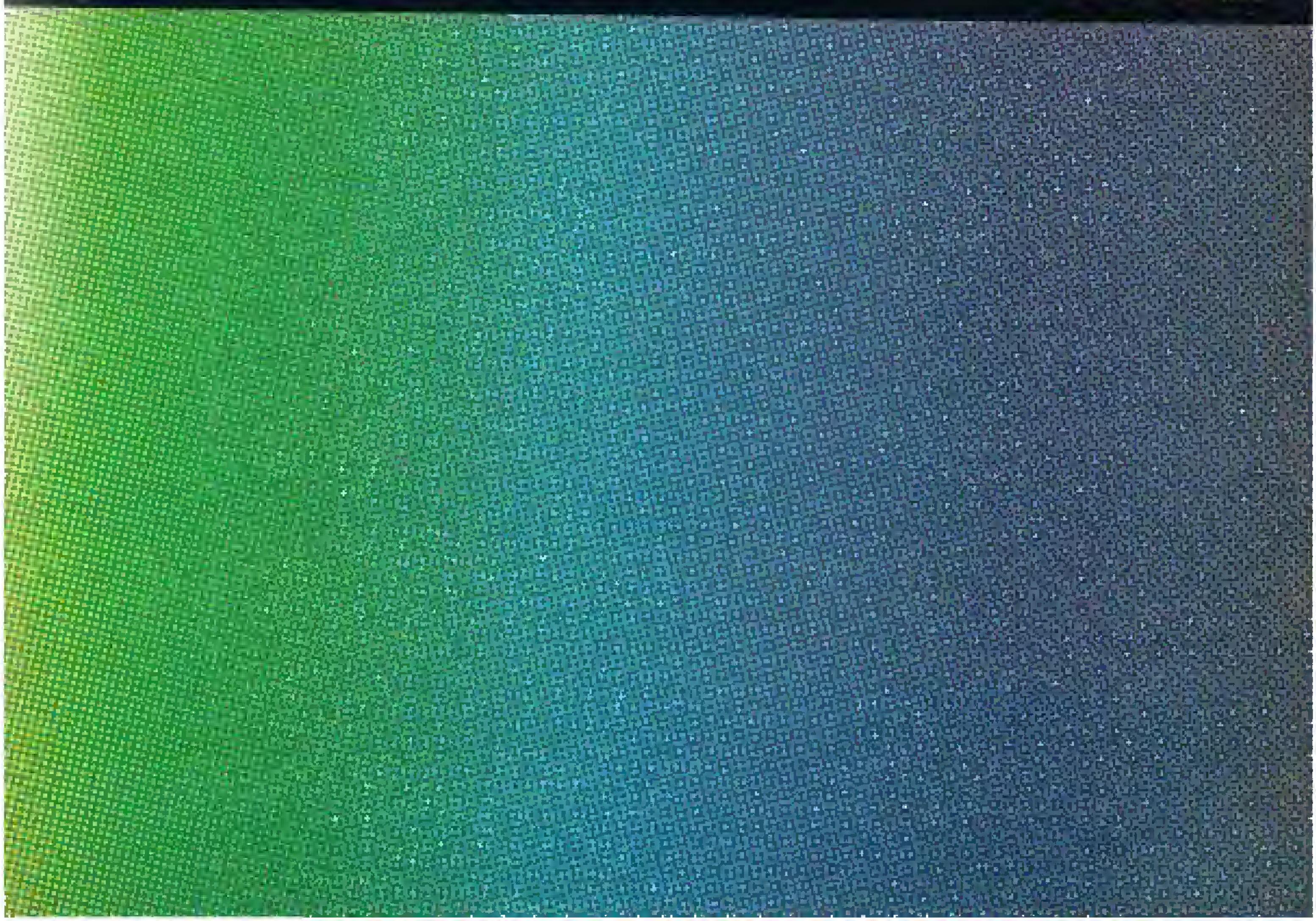
Chemistry Background Book

Colour



The main features of the eye are shown in this cross-section. Man is unique in his ability to perceive a wide range of colours; but this ability depends on an intense level of muscular activity which keeps our eyes quivering slightly. If this were to be stopped we would have an insect-like view in that everything in our field of vision would appear brownish grey.

White light separated by a prism into its different colours. This separation comes about from refraction of the light as it passes through the prism, the violet light, with the shortest wavelength, being refracted the most and the red light, with the longest wavelength, the least.

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colour

The rainbow results from refraction of sunlight (as we stand with our back to the sun) by raindrops. Sometimes, as in this photograph, there is a fainter secondary rainbow around the first, caused by double reflection inside the raindrops. In this secondary rainbow, the colours appear in a reverse order.
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Millions of pounds are spent yearly on manufacturing paints and dyes and using them on every kind of product. Colour is an important part of our lives. We meet with few manufactured objects that have not been submitted to one colouring process or another.

As we have been seeing colours ever since we were born we are perhaps inclined to take them for granted, but it is one of the virtues of the artist and the scientist to be able to look at familiar things as if seeing them for the first time.

Think how unattractive the world would seem if we were suddenly deprived of our sense of colour and saw everything in greys like a black-and-white photograph. This is how a dog sees his surroundings, but dogs with their highly developed sense of smell live in an exciting world of scent. Smell is the dog's dominant sense, the one which most influences him in his daily life. A dog, so to speak, lives by his nose. In the same way, man lives by his eyes.

We use our sense of colour everywhere. When a traffic signal shows red we stop the car; when it is green we drive on. We distinguish things by their colours: that blue book, that red bus, that girl with green eyes. Vivid colours make things like flags more easily recognizable at a distance. In everyday life colour is often a form of language and, as with all forms of language, we soon learn to respond emotionally and intellectually to it, and to rely on our responses. We respond to colour when looking at a painting, or when in the laboratory watching a piece of litmus paper change colour. Try comparing a black-and-white reproduction of a painting with its original in an art gallery and see if you can explain the difference. What is missing from the photograph?

How do we see colours? Do we all see the same colours? And what is colour?

part 1
the nature of colour

Vision – When we see things, what we really see is light reflected from matter. This is how we discern objects, unlike bats, who discern objects by hearing sound reflected from them. When we see colours, we are in fact reacting to coloured light.

The ability to react to light and to distinguish colours is probably connected with the development of consciousness in living creatures. Some very simple organisms exhibit sensitivity to light, moving towards or away from it. Others, like the worm, have developed patches on their bodies which are chemically sensitive to light. The earliest fossil remains to give an impression of true eyes are the trilobites, which flourished in the Cambrian seas about 500 million years ago.

The pattern of colour vision varies from one animal to another. We can identify the colours animals see by experiments in which food is put on differently coloured discs, or behind differently coloured doors. One of these experiments is described on the opposite page. Apart from primates such as monkeys, most mammals are completely colour-blind; their eyes, in varying degrees, are adapted to simple vision rather than to the perception of colour. A red rag to a bull really appears pale grey: it is the brightness, not the colour, that infuriates him, and a white rag would be even more effective. Nearly all birds have difficulty in seeing blue and they do not see violet at all.

The retina – the part of the eye which corresponds to the sensitized film of a camera – usually contains two different kinds of cells in different combinations. Cells of one kind, known as rods, respond sensitively to light, and eyes well endowed with them can see by moonlight and even starlight. The eyes of owls have a large number of rod cells in their retinas. The second kind of cells are known as cones, and are

An experiment to show that bees can see blue

A square blue card is put on a table in the garden. A watch-glass, containing a drop of syrup, is put on the card. After a short time, bees come to the syrup, suck up some of it, and fly back to the hive. They return to the syrup again and make the journey to and fro between the syrup and the hive several times. The watch-glass with the syrup is then removed, the blue card is shifted to the left, and a red card is placed on the right: there is nothing where the blue feeding card used to be. On the blue and red cards are put empty watch-glasses. When the bees return they fly straight to the blue card. It could not have been the scent of the syrup that attracted them – there was no syrup. It could not have been the position of the card they remembered—the card had been shifted. Therefore the bees must have been attracted by the blue and must be able to distinguish blue from red.

But possibly bees are colour-blind and see colours as shades of grey. To find this out, a blue card is put on the table, and is surrounded by grey cards varying from the extremes black to white. The watch-glass with syrup is put on the blue card and empty watch-glasses on the other cards. The bees come and go as before, and, after some hours, the blue card is shifted, and an empty watch-glass is put on it. The bees still go straight to the blue card, although one of the grey cards must have been of exactly the same brightness as the blue. Therefore bees really do see the colour blue. However, if this last experiment is repeated with a red card, the bees are confused. To bees, red is a shade of grey.

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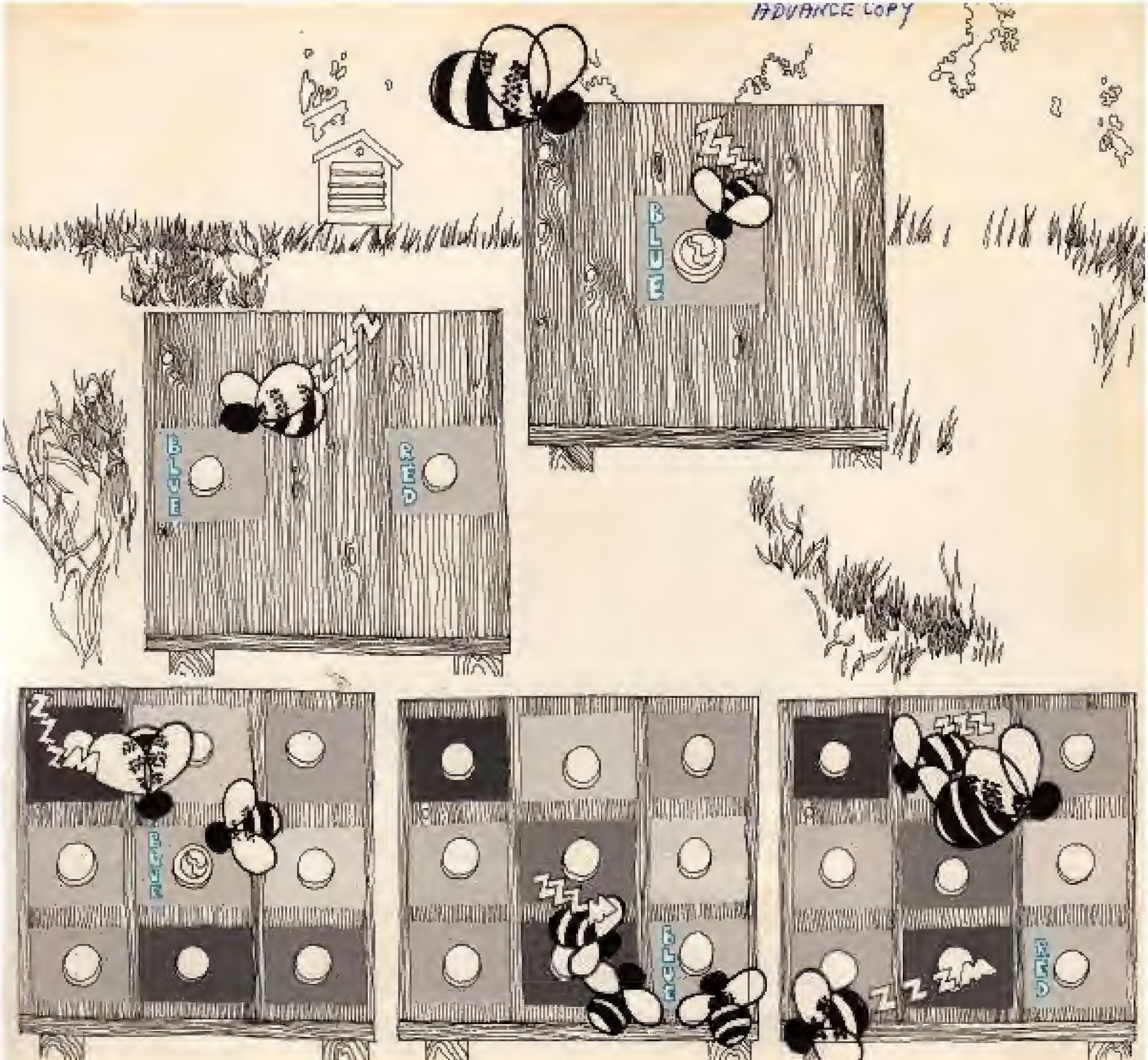
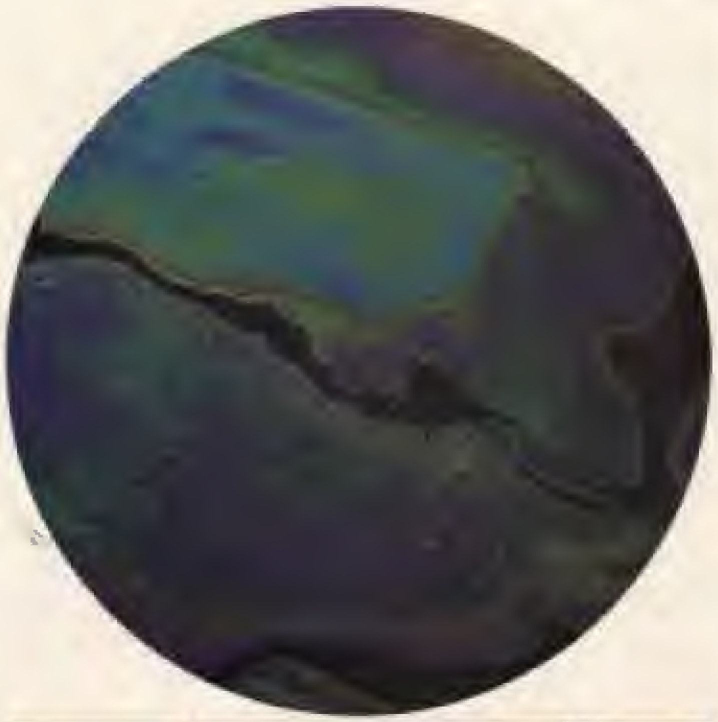


less sensitive to light. They can, however, distinguish colours. Most mammals have both rods and cones in the retina, but in man there is a small patch called the *macula* which is tight-packed with cones. It is probably this which allows us to see such a wide range of colours.

Coloured light – What is the difference between one colour and another? Why is red light red? Why is white light white? In what property of light must we search for these differences of colour? It is three hundred years since Isaac Newton laid the foundations of an experimental method for studying



Many colours are caused by interference effects – as in this oil film. Here, when the white light strikes the thin film of oil, some light waves are reflected from the top surface of the film and some from the bottom surface. The reflected waves may 'interfere' with each other and eliminate the colour of a particular wavelength – say blue. When blue light is subtracted from white light, the colour that the eye sees is yellow. Variations in the thickness of the film will result in the elimination of different colour wavelengths and our seeing different colours. Interference colours can be seen, for example, on soap bubbles and on the feathers of birds. They can be recognized because they change as we move. *Hayward Mitchell & Pavey Ltd.*

Spectra
Each element, when it is heated, produces a characteristic spectrum. The coloured lines in the spectra of substances reveal the elements they contain. Here are the spectra of some well-known metals – sodium, potassium, calcium, and barium. *J. W. Davis:* Advanced Level Practical Chemistry (*John Murray*)

the differences between light of different colours. This is how he described an experiment he carried out in 1666.

'I procured me a triangular glass prism, to try therewith the celebrated phaenomena of colours. And in order thereto, having darkened my chamber, and made a small hole in my window-shuts, to let in a convenient quantity of the sun's light, I placed my prism at its entrance, that it might be thereby refracted to the opposite wall. It was at first a very pleasant divertisement to view the vivid and intense colours produced thereby . . .'

Nearly 150 years later came the discovery that colours exist that are invisible to man. In 1800 Sir William Herschel used thermometers to take the temperature of the sun's light refracted through a prism, and was surprised to find that the hottest part occurred outside the red band of the spectrum. On a sunny day you can very easily repeat his discovery of infra-red radiation.

The following year a German scientist, Johann Ritter, was studying the chemical reaction caused by exposing silver chloride to sunlight. He found that, while violet was the

Qualitative analysis
From the colours produced by adding chemical reagents to a substance, it is often possible to determine which elements are present in the substance. This is what you can see being done in the photograph on the left.

Flame Test
The flame test is a quick way of identifying a metal in a substance – although it only works for a limited number of metals. The photographs show flame tests for the following metals: lithium – red flame; copper – green flame.

visible light that caused the strongest reaction, there was a band beyond the violet which produced an even stronger one. He had discovered ultra-violet light. Bees, which are blind to red, can see ultra-violet as a colour.

Newton's observations with coloured light, and Herschel's and Ritter's discoveries can now be explained in terms of the wavelike property of radiation. As the rainbow shows in the sky, and as Newton showed in his laboratory, white light can be separated into colours – violet, indigo, blue, green, yellow, orange, and red. But this is far from being the whole picture, for the visible spectrum, we now know, is only part of a much larger spectrum. Beyond the violet (the short-wave) end are ultra-violet and then X-rays and gamma rays. Beyond the red (the long-wave) end there are infra-red and then radio waves.

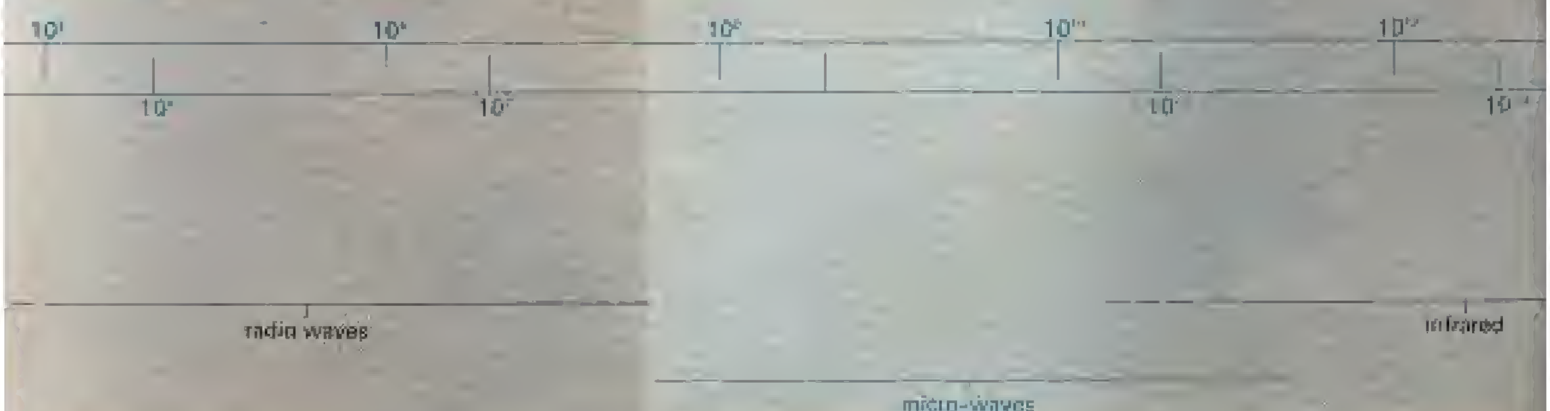
All these forms of radiation are called electromagnetic waves. They all travel at the same speed (the speed of light: $3 \times 10^8 m sec^{-1}$), and the only difference in their nature is their different wavelengths. The sections of the electromagnetic spectrum (radio waves, infra-red, visible, etc.) are not clearly separated; each type of radiation merges into its neighbours. There is no distinction, for example, between the longest infra-red waves and the shortest radio waves: if they have the same wavelength they are exactly the same in every other respect.

The fact that all electromagnetic waves have an identical nature may come as a surprise, since we know that different wavelengths have such very different effects. The shortest, gamma rays and X-rays, can penetrate through matter. Ultra-violet light causes sunburn. White light is the mixture of the wavelengths visible to the human eye. And then there is infra-red radiation – the carrier of heat – and radar and radio waves, all with different wavelengths.

Wavelengths are measured in a straight line from crest to crest of the waves. They can be very long or unimaginably short: the range is enormous. The gamma rays from radioactive substances are possibly the shortest waves: less than 10^{-10}cm. Try working this out in fractions of a millimetre. Radio waves are the longest: waves thousands of metres long are used in broadcasting. In between comes visible light from violet (41×10^{-6}cm) to red (65×10^{-6}cm).

The light from the sun comes from the hot incandescent

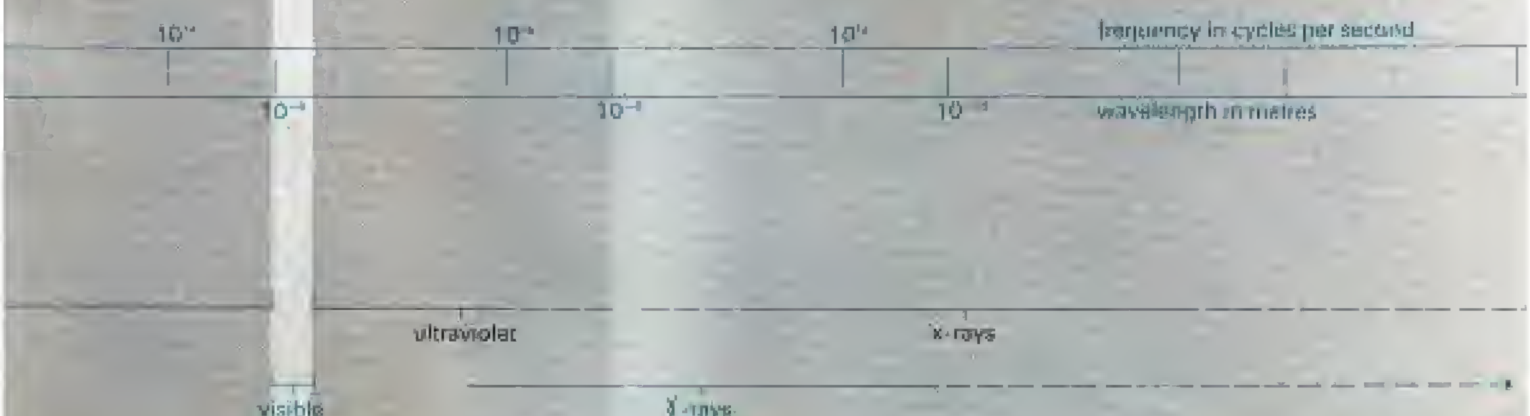
The Electromagnetic Spectrum
This is a continuous range of radiation spreading from gamma rays to radio waves. The radiation has the same velocity and physical nature throughout. Only the frequency and wavelength change from section to section.



gases on its surface. The light from an electric bulb comes from its hot metal filament. In both of them heat, one form of energy, is transformed into light, another form of energy. When a substance is heated sufficiently it will radiate visible light, but the wavelengths of the light will depend upon the chemical composition of the substance. Flame tests show this. If you heat a calcium salt in the flame of a Bunsen burner the flame will turn red, while a barium salt will make it turn green. Through a spectroscope the colours of light emitted by a hot substance can be distinguished with precision. Spectra, as these patterns of light are called, are often used to identify substances. The spectra of some well-known elements are shown on page 4. The spectroscope is illustrated in the Background Book, *The Chemical Elements*.

In towns where streets are lit with sodium vapour lamps, yellow cars and yellow window-boxes may look yellow, as will white surfaces. But everything else – even bright red pillar boxes – will look grey or black. The daylight world in which we live would appear very different if the Sun were made entirely of sodium.

Absorbing surfaces – In ordinary white light, the colours we see are usually decided by the properties of the surfaces which reflect light falling on them. When light falls on the surface of a substance, some wavelengths – that is, some of the colours – are absorbed. The rest are either reflected or, if the substance is transparent, passed through. On red surfaces, almost all except the red wavelengths are absorbed. On blue surfaces, nearly all except the blue wavelengths are absorbed. The colours we see are those which are not absorbed, but reflected. White surfaces reflect light of all colours to a similar degree; black surfaces absorb most visible light. On grey surfaces there is some reflection and some absorption of all the visible wavelengths. Sodium lamps make almost everything appear black or grey because the objects concerned absorb sodium light and do not reflect it. So the colour of a substance is determined by its capacity to absorb light of different wavelengths. Many living things are brightly coloured: the petals of a flower, the feathers of a bird, or the wings of a butterfly. What factors determine these colours? What is the 'green' of vegetation or the 'red' of blood? Most often, pigments are responsible, though sometimes colour is explained by interference effects (see page 4). In recent times, many



chemists have analysed the pigments to determine what they are made of. It has been found that they are organic materials with extremely complex structures.

It is not only the organic substances which are coloured, however. Nearly all the metallic elements reflect light of all colours to a similar extent, and therefore range in colour from white to grey. Copper and gold are exceptions. Colour is more evident in non-metallic elements. Chlorine is green; sulphur, yellow; bromine, reddish brown; and iodine, purple. Among the hundreds of compounds almost every colour can be found. Many of the metal oxides are coloured, for example, and so too are the sulphides. Most conspicuous of all are the compounds of the transition metals, nearly all of which are brightly coloured. However, there is no simple pattern to indicate which substances are coloured and which are not. The link between colour and chemical composition is not obvious. The explanation of the colour of a substance involves the electronic structure of its molecules, or of the crystal lattices in which the atoms and molecules are arranged.

Indicators
You will be familiar with the use of coloured substances to indicate the pH of solutions. Litmus and methyl orange are familiar examples. Another is phenolphthalein. It is colourless up to about pH 8 and pink beyond this. In the illustration an alkaline solution is being added to an acidic one and the point has just been reached where the pink colour appears. If a known volume of the acid solution is used, the volume of alkaline solution delivered by the burette enables a comparison of the strengths of the solutions to be made.

Chromatography

The separation of substances by chromatography depends on the use of solvents and adsorbents. But, as the name chromatography implies, it is colour that reveals the separation. If the substances are already coloured, as for example in chlorophyll, the separation is immediately apparent. If not, indicators must be used to bring out the colour differences.

Left – the separation of substances in chlorophyll and in three inks by paper chromatography.

Right – the separation of substances by thin-layer chromatography. The plate on the left has just been spotted with Congo red, bromothymol blue, phenol red, and a mixture of all three. The plate on the right shows separation of the mixture some twenty minutes later.

part 2
paints and dyes

Man has always shown great ingenuity in his search for colours to express his ideas and feelings and to brighten his surroundings. The bull from the Altamira Caves in Spain (see page 17) was painted over 12,000 years ago by an artist who had to make all his own pigments. The *Arnolfini Marriage* in the National Gallery (see page 16) was painted by the Flemish artist, Jan van Eyck, in the fifteenth century, using the new technique of oil on egg tempera. The artist is not only sensitive to shades and subtleties of colour to which most people are normally blind, but he can make us aware of what he sees. Here van Eyck has painted a number of *dyed* materials, the rich green of the woman's dress offset by the darker fur and cloth worn by the man, the bed hangings and the carpet, using *pigments* to express what he saw.

We use colours to decorate our homes and to brighten our clothes. Because of this constant demand for colours a large section of the chemical industry is devoted to manufacturing paints and dyes, the two main categories of coloured products. The difference between them is that paints form an opaque coloured skin on the surface to which they are applied and dyes are incorporated within the structure of a substance so as to change its colour. For practical purposes in use and manufacture, three qualities can be used to describe any colour accurately: hue, value, and chroma. These can be better understood by taking a watercolour box and mixing some paint on the palette.

Hue = the colour itself, whether red, yellow, or blue, etc.
Value = light and dark;
the amount of black mixed with the hue.
Chroma = strength or weakness;
the amount of medium (or white) mixed with the hue.

Plants from which colouring materials were extracted – especially for use as dyes.

SAFFLOWER

From the safflower, a red dye was extracted.

WOAD

The woad plant is the source of a blue dye used by the ancient Britons. Woad is similar to indigo which is an ancient dye blue that is now made synthetically but was formerly extracted from a plant that flourished in India.

DRAGON-TREE

From the cherrylike fruit of the Dragon Tree comes a dark red resin called dragonsblood. In olden times, this was extensively used as a red paint and also as a magic love incense. Today it is still used for tinting varnish. The name dragonsblood originates from a legend that, in a battle between a dragon and an elephant, the blood of the dragon was squashed onto the ground by the weight of the dying elephant.
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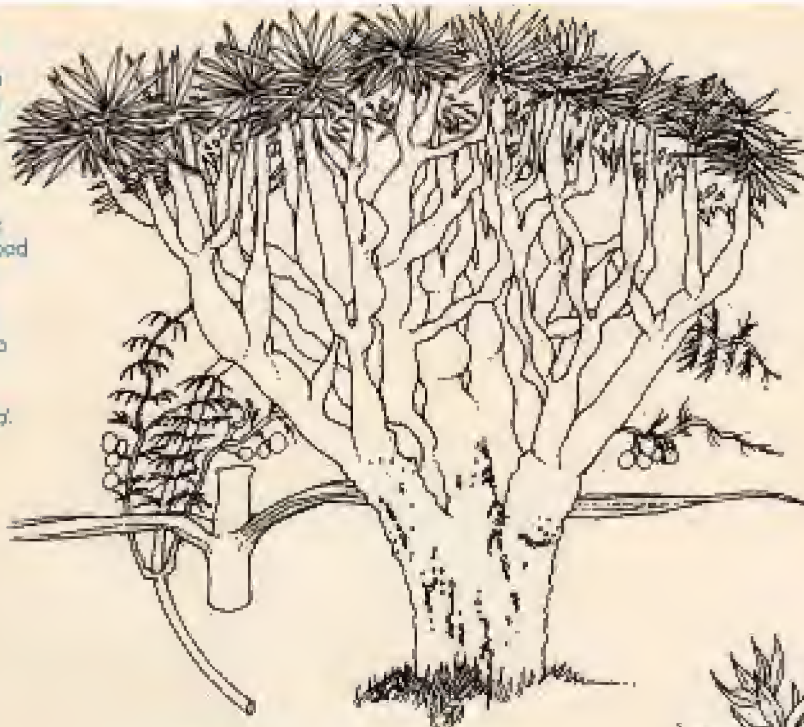
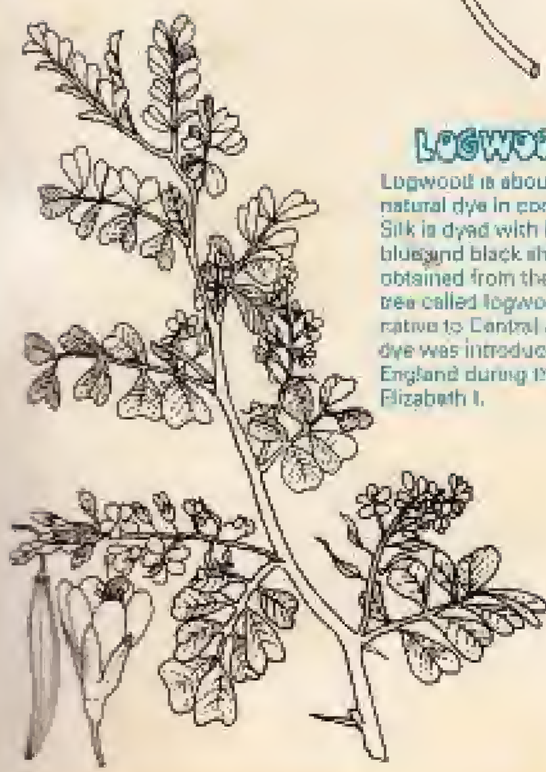


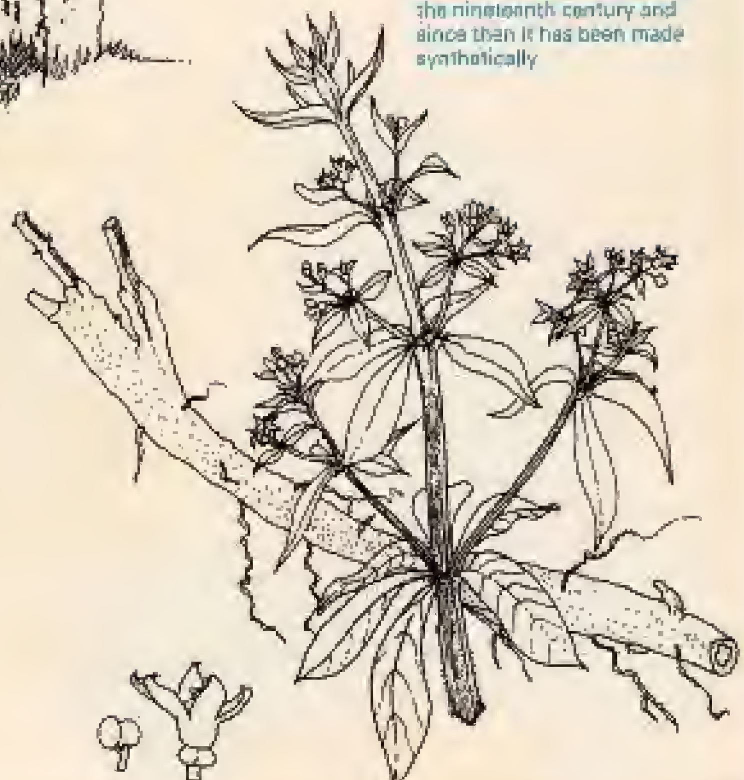
MADDER

Madder, a red dye obtained from the roots of the madder plant, was used by the ancient Egyptians. Turkey red was one of the many shades produced from it. The active colouring principle, 'alizarin', was extracted from it during the nineteenth century and since then it has been made synthetically.



LOGWOOD

Logwood is about the only natural dye in common use. Silk is dyed with it to produce blue and black shades. It is obtained from the wood of a tree called logwood that is native to Central America. The dye was introduced into England during the reign of Elizabeth I.



Paints–The majority of paints consist of finely ground particles of colouring matter, called the pigment, bound together by an oily liquid called the medium. When the paint is applied to a surface, the medium dries to form a hard film which binds the pigment particles to the surface. This hard and coloured film, as well as being decorative, is often used to protect the surface. Paint is used to protect, for example, the outsides of buildings against the weather, the walls and woodwork of kitchens and bathrooms against steam, and the metal hulls of ships against corrosion. Paints must therefore be made so that the films will adhere strongly to surfaces as different as concrete, wood, metal, and plaster.

Until the last century, all pigments and liquid media were natural substances. The earliest pigments were coloured earths or clays which had been stained by compounds of iron or manganese. These are still used by artists and have such pleasing names as yellow ochre, terre verte, raw sienna, raw umber, and Naples yellow. If the earths are burnt, they change to darker colours – burnt sienna and burnt umber. The great Dutch artist, Rembrandt, used mainly earth

The three primary colours of light are red, purple and green. From various combinations of these three colours – known as the additive triangle – all other colours of light can be produced. *Hayward Mitchell & Pavey Ltd.*

The three primary pigment colours – pink, blue and yellow – differ from those of light. They are known as the subtractive triangle because pigment colours result from the subtraction of colours from light. The three primary pigments can be combined to produce all other colours – as shown by colour printing. *Hayward Mitchell & Pavey Ltd.*

colours. Another pigment of early times is lampblack, made from charcoal. The Altamira and Lascaux cave paintings were done with natural ochres and lampblack made from oak charcoal, bound with a medium of animal fat, marrow, and blood.

Later, pigments were obtained from plants and animals – sepia from the cuttle fish, ivory black from burnt ivory, and indigo from the indigo plant. Compounds of metals other than iron and manganese were used to extend the range of colours. Potters looking for new glazes and the makers of stained glass windows made some discoveries. The names of many of these colours signify a metallic origin – cadmium yellow, zinc white, cobalt blue, etc. Flake white is made from white lead, and for a long time was the most widely used paint.

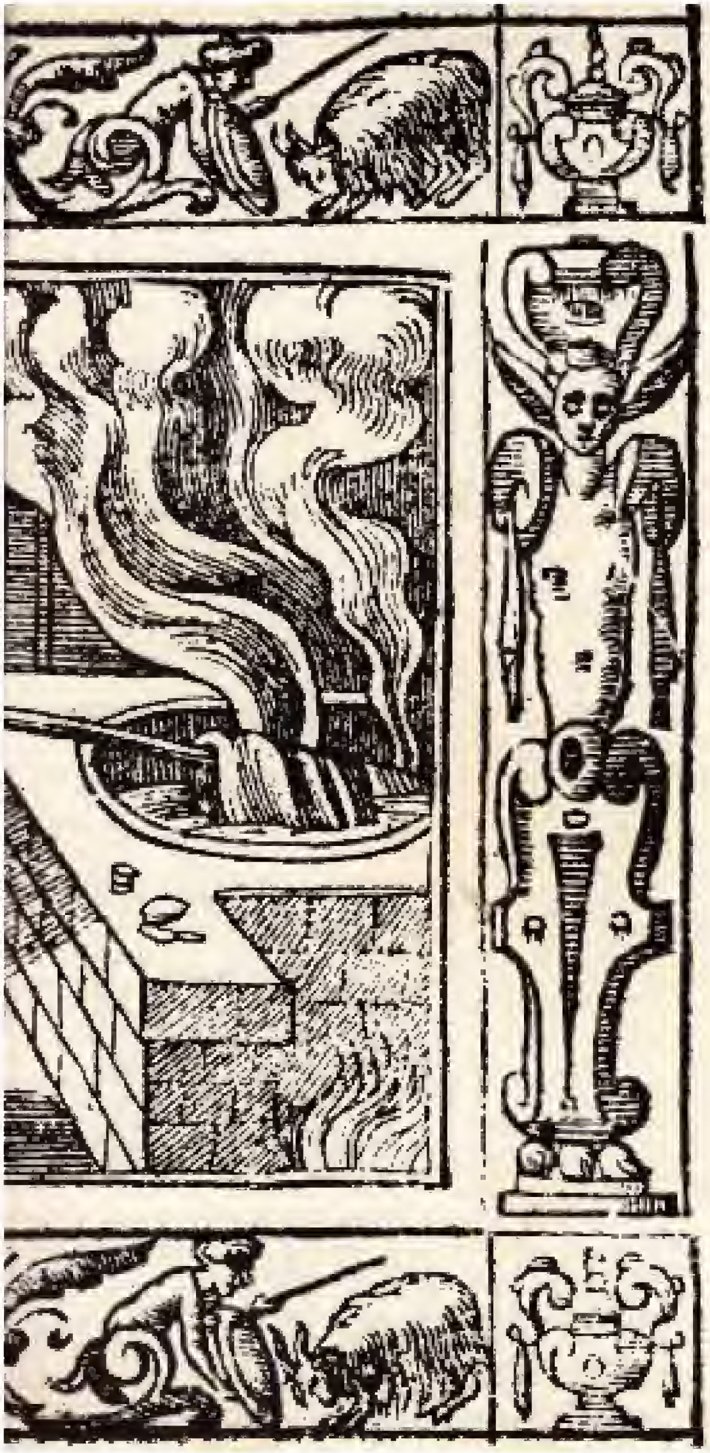
The first liquid medium was probably water; but more permanent ones were eventually discovered. Yolk of egg (used for a painting technique known as tempera) and poppy oil were among these. But, for many hundreds of years, linseed oil from the flax plant has been the most popular liquid medium – both for artists' paints and, until

To print pictures in full colour (as in this book), the paper must be passed through the printing machine four times – that is why it is much more expensive. The picture is first printed in yellow, then pink, then blue, and finally, to bring out the darker areas, black. Each impression must be carefully superimposed on the one before.

recently, for domestic and industrial paints. The structure of animal and vegetable oils is briefly discussed in the Background Book *Detergents*. They consist of a mixture of glycerides – glycerine linked with fatty acids. With drying oils such as linseed, the glycerides become oxidized on exposure to air to form a solid film. Linseed oil takes three or four days to dry, but the process can be greatly accelerated by adding small quantities of lead or manganese. By carefully heating the oil beforehand, it is possible to produce paint films that are hard and glossy. Paints made from oil treated in this way are known as enamels.

Another essential ingredient of most paints is a 'thinner' – to make the paint of a suitable consistency so that it can be applied with a brush. The 'thinner' must be a substance which is soluble in the liquid medium and which evaporates quickly from the painted surface. Turpentine, made from the resin of pine trees, has been used as a thinner for many centuries.

Pigments from metal compounds made into paints with linseed oil and turpentine were the basis of the paint trade until some fifty years ago. By then it had grown from a specialized craft in which the artist compounded his own colours to a huge industry supplying millions of gallons of paint for domestic and industrial use, but the ingredients remained much the same. Eventually the chemical operations which (as described below) had already brought great changes to the dye industry, were extended to the manufacture of paints. From the large number of dyes that the chemists synthesized, solid pigments were produced by precipitating the dyes with a suitable metal salt. Such pigments are called lake colours and, although the technique of turning dyes into pigments is not new, it is only within the last fifty years that paint



Dyeing in the seventeenth century. At that time, direct dyeing was unknown and the old methods of vat and mordant dyeing were the only ones in use.
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manufacturers have had a wide range of dye colours to choose from.

More recently, linseed oil in many paints has been replaced by a plastic material. Emulsion paints consist of particles of a plastic (usually polyvinyl acetate) dispersed in water. When the paint is applied to a surface the water evaporates or is absorbed, and the plastic particles coalesce to form a tough film. Other paints based on plastics are made from polyurethane and epoxide resin. Even the 'thinner', turpentine, has been largely replaced by a solvent called white spirit which is derived from petroleum. Only artists' paints remain substantially as they were; the newer synthetic paints, although durable, cheap, and excellent for general use, tend to lack the subtle tones of natural colours.

One problem in manufacturing a paint is to make sure that the solid matter is dispersed evenly in the liquid medium. This is done by adding a small amount of the liquid to the solid and grinding it to a smooth paste. In the old days, the artist did the grinding himself with a pestle and mortar; nowadays it is done in a machine. The paste is then mixed with the remainder of the liquid and the required amount of thinner is added. The solid particles should not be larger than the thickness of a coat of paint – a thousandth of an inch or so. As well as the pigment, the solid materials may include substances such as china clay which increase the surface area that the paint will cover without substantially affecting its quality. If the paint has to protect a surface against corrosion, such substances as red lead or zinc chromate are also added (see the Background Book, *Corrosion*).

Dyes – The main use of dyes is decorative – to colour fabrics. Unlike paints, which form films adhering to the surface, dye

This beautiful container known as the Lycurgus Cup is a fine example of fourth-century craftsmanship. The cup is green in reflected light and purple in transmitted light – one result of the way in which it was made. The different colours are created by suspended particles of gold in the glass which catch the light and reflect it. It is difficult to believe that so fine an object was made not by the modern technique of glass-blowing but by being moulded around a core of sand. The speed with which the molten glass needed to be worked must have made the exquisite mouldings on this cup very difficult to achieve. The Lycurgus Cup can be seen in the King Edward the Seventh Gallery at the British Museum. *Copyright, Trustees of the British Museum*

The Arnolfini Marriage by Jan van Eyck (*c.* 1390-1441). *National Gallery, London*

A cave painting of a bull at Altamira in Spain – painted over 12,000 years ago.
Michael Holford

Cleaning an old painting. Most paintings are given a protective coat of varnish – a transparent paint prepared by dissolving resins in either oil or alcohol. The varnish protects the painting from light that may cause the pigments to fade and from chemical attack by oxygen or other gases of the atmosphere. However, as the varnish ages, it becomes darker and less transparent. Therefore it must be carefully removed and a fresh layer applied.
Hayward Mitchell & Pavey Ltd.

Some of these pigments have been used by artists for thousands of years. The red and yellow are clays coloured by compounds of iron and manganese. The black is made from charcoal. The white is made from china clay.
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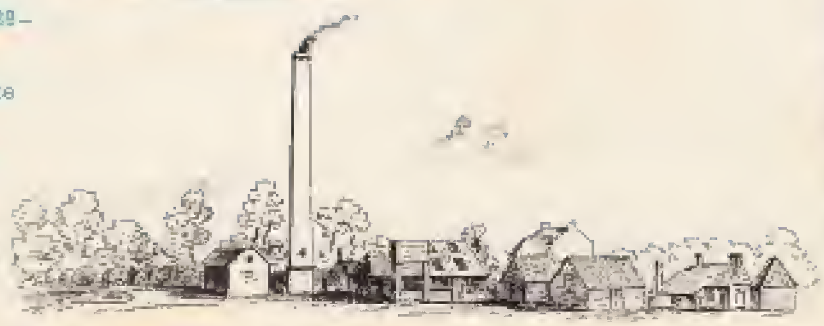
Sir William Henry Perkin (1838–1907) who, at the age of eighteen, made the first synthetic dye from a substance present in coal tar.
Crown Copyright.
Science Museum, London

A sample of the original 'mauveine' or 'aniline purple', prepared by Perkin.
Science Museum, London



A sketch by Perkin of his dye factory at Greenford Green in Harrow, Middlesex.
Science Museum, London

substances (or dyestuffs as they are called) are chemically linked to the fibres of the fabric. If they were not held 'fast' in this way, they would soon wash out.

There are many methods of dyeing which vary according to the chemical nature of the dye and the fabric. All of them involve the use of dyes that are soluble in water. In direct dyeing, which has been possible for less than a hundred years, the fabric is simply boiled in a solution of the dye. Mordant dyeing involves a third substance, usually an aluminium compound, which forms intermediate links between the fibre and the dye. Mordants (biters) provide surfaces on which dyes will hold fast. In vat dyeing, the fabric is soaked in a colourless solution of the dye and only when it is exposed to the air does the colour form.

The art of using dyes to colour fabrics is almost as old as the art of painting. In ancient times, dyes were extracted from plants and animals. The Egyptians and Assyrians, the Greeks and the Romans were skilled in the art. The cities of Tyre and Sidon were famous for their purple dye which was extracted from the shellfish, *murex brandaris*. Indigo blue was extracted from the woad plant. The 'safflower' and the 'weld' gave red and yellow dyes and *rubia* the red dye known as madder. Vat dyeing and mordant dyeing were used to colour fabrics. Great skill is needed to carry out these operations but despite the fact that success depends on chemical reactions that were not then understood, fine results were achieved. Some of the vegetable dyes were extremely 'fast', and, although there were only a few of them, a useful range of colours was made by mixing the dyes or by using various mordants. Nowadays, logwood is the only natural dye in widespread use.

Modern dyes are synthetic – made in the laboratory. Some are structurally similar to natural dyes but most have no likenesses in nature. Synthetic dyes date from the discovery of a 'mauve' dye by W. H. Perkin in 1856. Perkin entered the Royal College of Chemistry at the age of fifteen in 1853 and was set to study some reactions of anthracene. This, like many of the substances being investigated at this time, was obtained from coal-tar. Perkin set about his work with great enthusiasm, carrying out much of it in a 'home laboratory' which had neither piped water nor gas. During the Easter holiday of 1856, Perkin attempted to make the drug quinine. We know now that the method he used could not succeed because it was based on imperfect ideas about the composition and structure of the substance.

He first obtained a reddish-brown precipitate. It looked unpromising, but Perkin repeated the reaction with a different starting material and produced a black solid mixed with a small amount of a purple one. He then separated the purple substance and found that it had some of the qualities needed for a dye. If the story had ended there it would be very much to the credit of an eighteen-year-old chemist, but there is more to tell. Perkin proceeded to manufacture the material, and his great contribution was the production of an 'artificial' dye in quantity. Called aniline purple, or mauveine, it became immensely popular. Clothing dyed with it was the height of fashion. Later on it was used to dye the 'lilac' postage stamps of the period.

This success was not luck. Before starting the manufacture of his dye, Perkin consulted the dyeing firm of Messrs Pullars of Perth. They carried out tests on his material which gave encouraging results. He had grounds for hope, therefore, and in spite of many difficulties he set up a factory at Greenford Green, at that time a village in open country in the parish of Harrow, Middlesex. By the end of 1857 it was in production. When the factory was sold in 1874 it was producing several dyes besides the original mauve. This period saw a transition from the trial-and-error search for dyestuffs to a more systematic approach based on a better understanding of their nature.

After Perkin's original discovery came the synthesis of a natural dye, when Graebe and Liebermann made alizarin (the active colouring matter in madder) starting from anthracene. By this time the structure of benzene had been worked out by Kekulé, and many advances were possible. The benzene ring of six carbon atoms, with hydrogen atoms joined to them, is a feature of the structure of the molecules of very many dyestuffs. Without a knowledge of it, the structures of many dyes remained obscure. But afterwards it was apparent that certain groups of atoms in dyestuff molecules were responsible for the colour and that others, though not causing colour by themselves, helped in its production.

Thus there grew up a great industry producing synthetic dyes from the organic chemicals found in coal tar. Tens of thousands of dyes have been synthesized and thousands of these are produced commercially. Germany first took the lead

Skeins of wool after they have emerged from the dye bath.
Hayward Mitchell & Pavey Ltd.

The murex whelk from which the famous dye Tyrian purple was obtained. The animal was picked out of the shell, and the shell was ground in a mortar and processed to make the dye. Variations in colour were produced by using different species of whelk.
Hayward Mitchell & Pavey Ltd.

The many different colours that go into the weaving of an Axminster carpet.
Hayward Mitchell & Pavey Ltd.

in building up this industry and won a commanding lead by the synthesis of the natural dye indigo. The best part of thirty years had been spent to find a way of making a synthetic indigo that could compete in price with the natural product and the cost of the research was very great. But by the end of the nineteenth century, synthetic indigo could be sold for less than the natural product.

When the First World War cut off supplies of the dyes and other chemicals which came from Germany, other countries were forced to start making

Colour for fashion: In this picture Twiggy is wearing a pure new wool sweater and skirt carrying the Woolmark. Dyes are used extensively to colour clothing materials and produce today's bright colours.
International Wool Secretariat

Monastral Fast Blue

In 1932, a chemist working at the Grangemouth factory of I.C.I. discovered a new pigment. He was concerned with making phthalimide — a stage in the manufacture of indigo — and was puzzled by a greenish blue discoloration in certain batches of the product. A minute quantity of the impurity was isolated, and analysis showed it to be an organic compound (phthalocyanine) of iron — formed from a fine crack in the enamel lining of the cast iron reaction vessel. Other metallic derivatives of the compound were later prepared, and it was found that the copper compound gave a stable pigment of a rich blue shade.

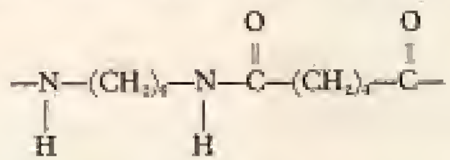
The molecular structure of the compound was determined by Professor Linstead and his co-workers at London University, and thereafter industrial progress was rapid. Copper phthalocyanine was manufactured under the name of Monastral Fast Blue B, and this and related phthalocyanine pigments are extensively used today for colouring paints and printing inks, plastics, rubber, leathercloth, paper, and many other articles.

The blue in this page is Monastral Blue.

Within the last fifty years nearly all the colours that are used as dyes or in paints have come to be made synthetically. It is the chemist who has made this possible. Here is a laboratory in which dyes are prepared. They can be seen in the bottles in the foreground of this picture.
Geigy

their own. Afterwards the British chemical industry achieved many successes. Among them was the discovery of Caledon Jade Green in 1920, and of methods for dyeing the synthetic fibre cellulose acetate during the 1920s. Another important advance came with the discovery of the phthalocyanine pigments. This, like Perkin's discovery of mauve, came about as the result of the persistent pursuit of a chance discovery. The first of these colours, called Monastral Blue, was marketed in 1934. As well as in dyes, it is used in paints, for colouring plastics and rubber, and for colour printing of paper.

One of the problems of dyeing has always been the fixing of the dyestuff to the fabric. Dyes, found in the past to be excellent for wool, silk, or cotton, may be of no use at all with the new synthetic fibres. Fortunately the chemical structure of these fibres is known, so that a guess at a suitable dye can often be made. For example, in the repeating unit of nylon



shown in the diagram, the hydrogen atom joined to a nitrogen atom provides a point at which a dye molecule with acidic properties can be attached. Should a new fibre be found to have no suitable points for fixing the pigment, the fibre may even be altered slightly.

The need for colour – We have seen something of the huge effort of invention and manufacture that goes into the making of paints and dyes. But why do we need these colours? What effect do they have on us? They seem to be a kind of food for our emotions and moods, just as important to us as food for our bodies. We need them to make us lively and cheerful. Shut yourself in a darkened room and stay there for a long time and your mood will probably be black. Go out into the sunshine and notice all the subtle effects of colour, light, and shade, and you can feel the change for yourself. The more attention you pay to colours, whether as artist or as scientist, the more enjoyment you will gain from them. Even looking up from this book, after thinking about colours, you will probably be aware of an extra brightness in the world around you.

Plant for manufacture of dyestuffs.
Geigy

The essential ingredients of a pot of paint are particles of pigment bound together by a liquid medium, and a 'thinner' to make the paint easier to apply. The pigment may be a synthetic lake colour or a metal compound. The medium may be linseed oil or water or a plastic material. The thinner may be turpentine or white spirit or, with emulsion and water-bound paints, water. Here is a mill in which solid pigments are ground to a fine powder and mixed with the liquid medium to form paint.
James Anderson & Co. (Colours) Limited

Testing pigments (far left) for coating paper and (left) for use as printing inks.
Geigy

On the cover of this book you can see demonstrated the screening process which a printer uses when he is working in four colours. The screen for each colour (a criss-cross mesh) is overlaid on its predecessor at a different angle. If this were not done the final result would look 'muddy' and lack definition.

On its orange background the star looks dull red, but when it is set in the midst of a turquoise it seems a much lighter shade. In fact both stars are the same shade exactly, so the effect which you experience is an optical illusion. Colour theories of which this effect is a by-product had a great influence on painting between the wars. The German poet and philosopher Goethe developed a theory of colour and perception which was taken up by painters and teachers of the German Bauhaus school. Vassily Kandinsky, Paul Klee, Johannes Itten and Joseph Albers were all influential in developing these new ideas.

Chemistry Background Books
General editor H P H Oliver Author of this book N R Waite
Art editor Ivan Dodd
Published for the Nuffield Foundation by Longmans/Penguin Books
Longmans Green and Co Ltd London and Harlow
Penguin Books Ltd Harmondsworth Middlesex England

First published 1969
Made and printed in Great Britain by Newgate Press Limited

CBBO4337